

# CapKey+

## An improved PIC-based capacitive sensor-paddle for electronic Morse code keyers

### the sensor-paddle evolution

Early sensor-paddles used by radio amateurs worked with the skin resistance, which is a widely varying parameter and makes two electrodes necessary - in the form of split or meandering electrodes or solid electrodes and a conductive hand pad. They were notoriously unreliable and no pleasure to operate, and that's why they gained a bad reputation.

Being a passionate high-speed CW operator, in the late 1990s I had the idea for a sensor-paddle based on the *self capacitance* of the human body, which has a much more settled value about 100 - 200 pF. Imagine a 40 x 30 mm conducting sensor plate covered with a protective 0.1 mm self-adhesive plastic foil. It has a typical capacitance of less than 5 pF which increases by about 2 pF when it is lightly touched with a finger. It follows that irrespective of its principle of operation a sensor-paddle must be able to reliably detect a capacitance change of merely 2 pF, which is not a trivial task.

So I developed a simple circuit around two CMOS ICs 4093 / 4013 with an 18 KHz square wave charging and discharging the sensor capacitance through a

variable series resistor for sensitivity adjustment. Touching the sensor increases its capacitance and so the time constant of this series RC network. The result is an increased rise / fall time of the voltage at the sensor capacitance, and if it lags the edges of the square wave by a certain amount a touch of the sensor is detected.

This initial circuit proved to be reliable and precise in operation, and furthermore one single electrode per sensor now did the job - no slits or meanders, no conductive hand pad was necessary and the sensors could even be varnished or covered with plastic foil. Since then all my mechanical paddles collect dust because I do not use them any more. However, it turned out that it worked without problems only in my preferred keying mode, which is plain iambic without dot/dash-memory, but regardless of the keyer used it did not allow modes with dot/dash-memory (iambic type A = Curtis-keyer / type B = Accu-Keyer and ultimatic). The reason is that in these modes the paddle is polled while the transmitter is keyed, and even very low levels of radiated HF coupled into the circuit simulate a touched sensor already when a finger is brought only close to it.

My second circuit appeared in 2004. It was based on a design by Milt Cram, W8NUE, which used the LTC1043 (a quite expensive switched-capacitor instrumentation IC) together with a dual op-amp LMC 6462 and worked with the capacitance between two electrodes which increases when they are touched<sup>1</sup>. I modified Milt's design so that it works with the human body's self capacitance to ground and therefore needs only one single electrode per sensor, exactly as my initial circuit did. However, its principle of operation is totally different: the sensor capacitance  $C_S$  is alternately switched at a rate  $f_0$  of about 50 KHz between the supply voltage  $V$  and the parallel RC network of a 22 nF reservoir capacitor  $C_R$  and 100 K $\Omega$  resistor  $R_R$  so that the circuit works as a switched-capacitor charge pump. 50,000 times per second the very small switched (or "flying") sensor capacitance is at first fully charged to the supply voltage and then it dumps its absorbed charge into the large 22 nF reservoir capacitor, which is like filling a large water basin with a small bucket.

The switched sensor capacitance may be considered to be equivalent to a resistor  $R_S$  with a value of  $1 / (f_0 C_S) \Omega$  which together with the 100 K $\Omega$  reservoir resistor  $R_R$  works as a resistive voltage divider, so that the voltage across the parallel RC network settles at a value of  $V \times (R_R / (R_R + R_S))$ . It takes many cycles until this voltage is reached, but after that initial charging phase it follows small changes of the sensor capacitance quite rapidly, so that by comparing it with an adjustable reference voltage the touch of a sensor

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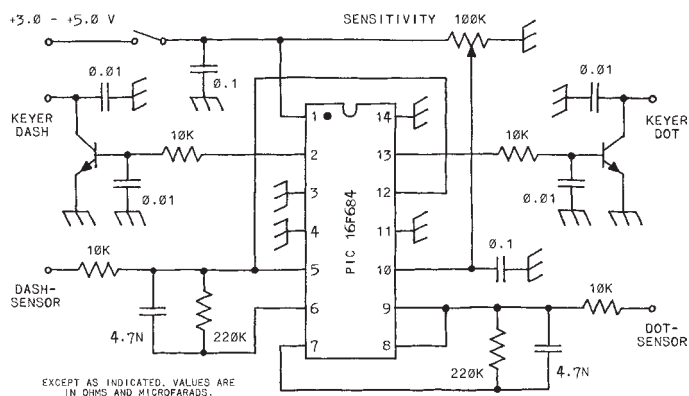
can be reliably detected. And because fast time-varying signals are effectively absorbed by the large reservoir capacitor  $C_R$ , this charge pump approach has a high intrinsic immunity to radiated and conducted HF, so that it can be used in any keying mode.

Both circuits soon became quite popular among German CW operators, printed circuit boards appeared on the scene and even completely assembled keyers were manufactured and offered by radio amateurs. Capacitive sensor-paddles gained popularity also abroad and a number of articles were published in amateur radio magazines. Simultaneously industrial sensor applications became widespread with specialized ICs appearing on the market. One popular example is the QT113, a charge-transfer touch sensor IC made by Quantum / Atmel. However, the response time of this sensor is typically in the order of tens of milliseconds and it also exhibits a threshold hysteresis between "make" and "break" which makes it well suited for controlling electric devices but less for serious high-speed CW operation.

In 2011 I developed *CapKey*, a capacitive sensor-paddle based entirely on software logic utilizing one single 8-pin PIC 12F683 microcontroller instead of discrete and specialized ICs. Being self-calibrating it needed no adjustments and responded about 100 times faster than the QT113 without any hysteresis. The sensor capacitance is cyclically at first quickly discharged and then charged through a large 1 M $\Omega$  resistor while a charge counter is incremented in steps of 0.5  $\mu$ s until the voltage at the sensor equals about half of the supply voltage. And if the charge counter exceeds the calibration counter of the untouched sensor by a certain amount, a touch of the sensor is detected.

This principle of operation is able to detect very small changes of capacitance very quickly, but it has a drawback: the positive halfwaves of even very low levels of radiated HF coupled into the circuit interrupt each charging cycle at its very beginning and thus inhibit the detection of a touched sensor. A large capacitor in parallel with the sensor which could absorb fast time-varying signals is not feasible, because contrary to the charge pump approach it must be cyclically charged through the 1 M $\Omega$  resistor (of which the value can not be reduced without degrading the sensitivity), and therefore the time constant and with it the response time would vastly increase. So again like my very first CMOS circuit it worked without problems in plain iambic mode but did not allow modes with dot/dash-memory.

What follows is the description of the latest evolutionary step, its improved successor *CapKey+* which now emulates the charge pump approach based on the modified design of W8NUE. One cheap 14-pin PIC 16F684 microcontroller replaces the 18-pin LTC1043 and 8-pin LMC6462 in a very simple circuit with only few discrete components. And it has the same high



intrinsic immunity to radiated and conducted HF, so that it can be used in any keying mode.

## circuit details

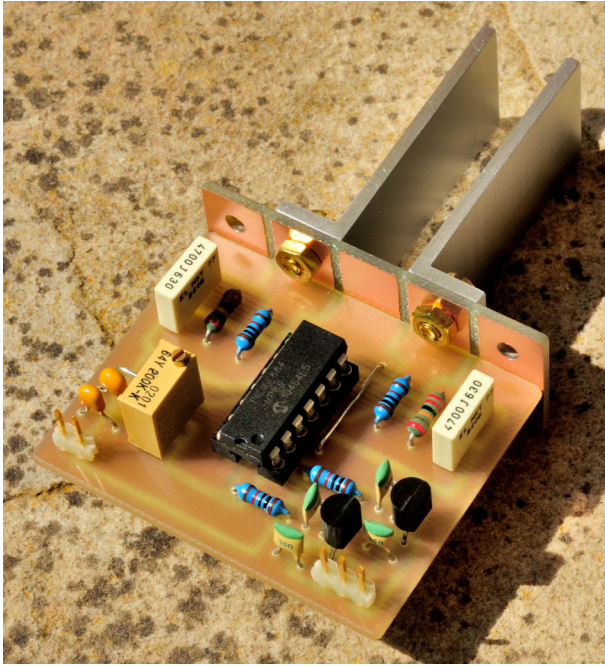
The circuit is shown in the above figure, programmed PICs 16F684 are available from the author and the firmware hex-file can be downloaded <sup>2</sup> for personal non-commercial use. The supply-voltage has a range of 3.0 to 5.5 V, I recommend 3 AA batteries giving 4.5 V with a current drain of approx. 1 mA which is very low but still makes a switch necessary. Duracell MN1500 batteries for example should provide more than 1000 service hours. The transistors are general-purpose NPN types. Only if the controlled keyer is powered by the *same* voltage source, the two transistors together with their 10 K $\Omega$  base resistors can be omitted and pins # 2 and 13 connected directly to the associated keyer inputs with only one 10 nF bypass capacitor from each pin to ground. The firmware detects pulled-up keyer inputs and delivers active low signals to pull them down instead of active high signals to make the transistors conduct. The sensitivity trimpot is a multi-turn type for higher adjustment resolution, its value is not critical but should be in the range 50 K $\Omega$  to 1 M $\Omega$ . The two 4.7 nF reservoir capacitors must be high quality film / foil caps, do *not* use cheap ceramic capacitors instead. The 10 K $\Omega$  resistors to the sensors were added to further improve HF immunity by forming an RC low-pass filter together with the large reservoir capacitors.

In order to work reliably, the circuit must be able to make use of the human body capacitance to ground or at least to a substantial conductive structure. Therefore paddle-ground must be connected to station-ground which is usually provided by the shield of the keying line.

## construction notes

Because the circuit is so simple and construction straightforward, no detailed description and no circuit board layout are presented here. Instead of an etched board you can use a small piece of perfboard, or use single-sided circuit board material and mill out the copper traces with a dremel tool as I did with my pro-





Prototype shown from rear top (above) and rear bottom (below). Two single-sided PCBs are solder-joined forming a "T", one holds the sensors and the other one holds the circuit. The sensors are made of anodized aluminium angle stock. The copper traces were milled with a dremel tool.



prototype shown on the above pictures - my preferred construction method for simple circuits. But do *not* try to use a solderless plug-in bread-board (plug-board), because the significant stray capacitance and hence coupling between its connection strips makes it impossible for the circuit to work reliably.

The sensors plates can be made of any conductive material, for example aluminium stock or single-sided circuit board material. In the latter case, the copper should be varnished or covered with self-adhesive

plastic foil with max. 0.1 mm thickness, otherwise the copper will be worn off after only a few months of intensive use. Varnish or plastic foil reduces the sensitivity, but the paddle still works perfectly well. The sensor plates can be of any shape, but because the capacitance between them should not be higher than approx. 1 pF the following relations between sensor-area  $S_a$  and sensor-clearance  $S_c$  must be satisfied:

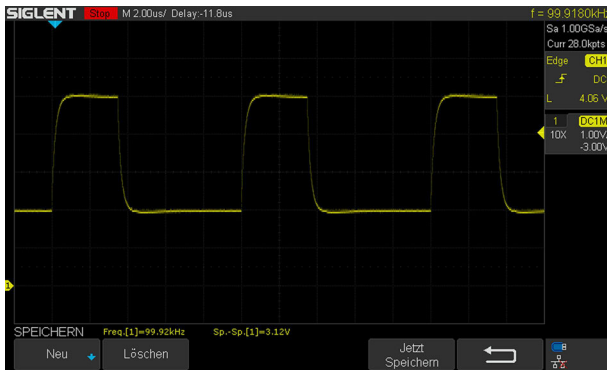
$$\begin{aligned} S_a [\text{mm}^2] &\leq S_c [\text{mm}] \times 113 \text{ mm} \\ S_c [\text{mm}] &\geq S_a [\text{mm}^2] / 113 \text{ mm} \end{aligned}$$

For example, if each sensor has an area of  $40 \times 25 \text{ mm} = 1000 \text{ mm}^2$  as in my prototype shown on the pictures, their clearance should be at least  $1000 \text{ mm}^2 / 113 \text{ mm} = 9 \text{ mm}$ . If both dot and dash are triggered when only one sensor is touched, the sensor area  $S_a$  must be decreased or the clearance  $S_c$  increased.

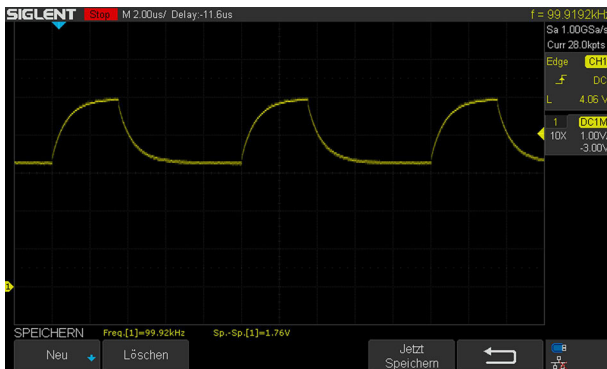
Please note that the circuit traces and wires which are in contact with the two sensors are also touch-sensitive and increase their capacitance, which when untouched should be as low as possible and differ by the least possible amount in order to get about the same sensitivity for both. Therefore the surface area of these traces and wires should be as small as possible and they should have a clearance of at least 5 mm to conductive cabinet parts. Furthermore, the layout of the traces and wires connecting pins # 5 and 9 with the sensors should be as symmetrical as possible. If wires are used to connect the sensors with the circuit, they should be stiff, as short as possible and at least 5 mm away from each other and from other conductive parts.

Sensitivity adjustment should be done with the keyer connected to the transmitter, so that paddle ground is connected to station ground by the shield of the keying line. Set the keyer to iambic type A or B mode. To check the sensor capacitance symmetry leave both sensors untouched and adjust the trimpot so that only dots or only dashes are just starting to be generated, then advance the trimpot so that both dots and dashes are just starting to be generated. The smaller the difference between these two setpoints the better the symmetry of the sensors. Finally adjust the trimpot so that dots and dashes are reliably generated as long as the associated sensor is lightly touched.

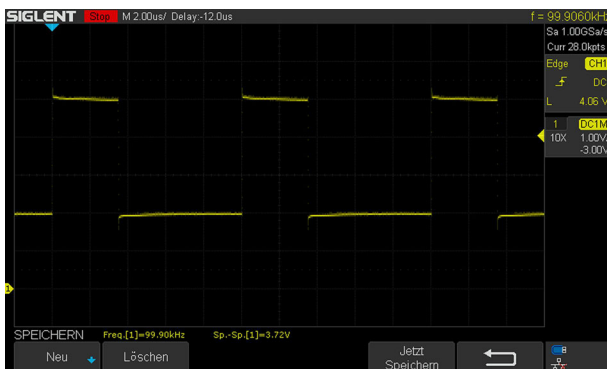
The oscilloscope screenshots on the next page visualize the operation of the circuit and can help you to troubleshoot it. A unique PIC-based multi-mode Morse code keyer that works perfectly together with this capacitive sensor-paddle is described in my article "*Keyrama*"<sup>3</sup>.



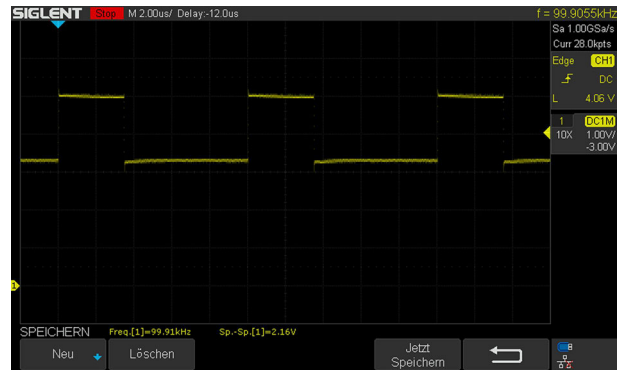
Probe connected directly to an *untouched* sensor plate, the voltage varies between +5.0 V (supply voltage) when the sensor capacitance is fully charged and +2.0 V (voltage at the 4.7 nF reservoir capacitor measured through the 10 K $\Omega$  resistor) when it has dumped its absorbed charge into the reservoir capacitor. The sensor capacitance is charged / discharged through the 10 K $\Omega$  resistor and the time constant of this series RC network causes the deviation from an ideal square wave. The horizontal scale is 2  $\mu$ s / div. so that one complete cycle takes 10  $\mu$ s which gives a rate of 100 KHz.



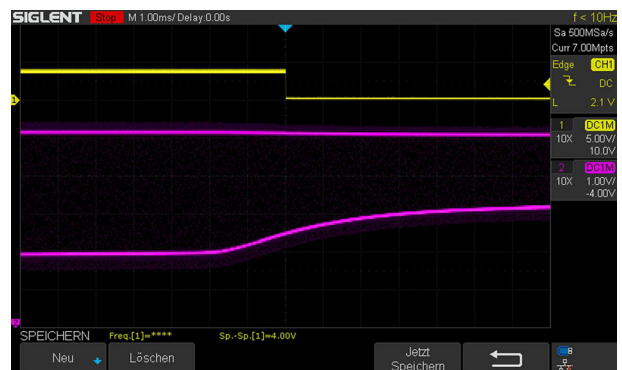
Now the sensor plate is *touched* and its increased capacitance causes a higher voltage of +3.2 V when it has dumped its absorbed charge into the reservoir capacitor. The time constant of the touched sensor increased significantly so that charging takes more time, but it can still be charged to the full supply voltage of +5.0 V.



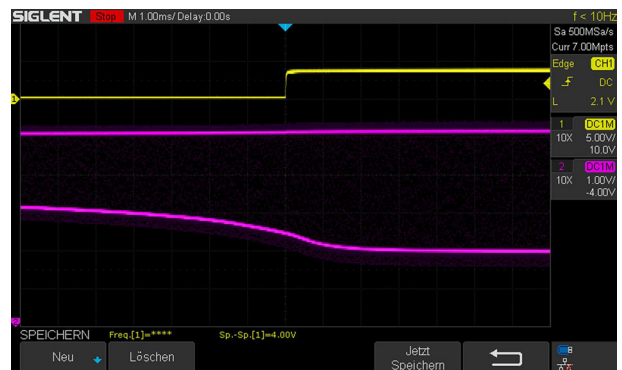
Probe connected to a 4.7 nF reservoir capacitor which is charged by an *untouched* sensor plate. The voltage of the square wave alternates between a high value of +5.0 V (supply voltage) while the sensor capacitance is charged and a low value of +2.0 V when it has dumped its absorbed charge into the reservoir capacitor.



Now the 4.7 nF reservoir capacitor is charged by a *touched* sensor plate and its increased capacitance causes a higher voltage of +3.2 V when it has dumped its absorbed charge into the reservoir capacitor.



Two probes connected to a 4.7 nF reservoir capacitor (magenta) and to the associated pulled-up keyer input (yellow). Note that the scale is now 1 ms / div. so that what looks like two magenta traces is actually only one single trace of a square wave alternating between its low and high value like on the two previous screenshots. About 5 ms from the left edge of the screen the associated sensor is touched and the low value of +2.0 V starts to rise, after 2 ms ("make" response time) the touch is detected at a threshold of +2.5 V and the keyer input goes down.



At the left edge of the screen the associated sensor is released and the low value of +3.2 V starts to fall, after 7 ms ("break" response time) the release is detected at the same threshold of +2.5 V and the keyer input is pulled up again.

## references

1. Cram, Milt, W8NUE, "The NUE Key - An Electronic Touch Sensor Paddle", QST, July 2004, page 28.
2. <http://cq-cq.eu/capkey+.hex> (click URL to download)
3. [http://cq-cq.eu/DJ5IL\\_rt008.pdf](http://cq-cq.eu/DJ5IL_rt008.pdf) (click URL to open)

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